SUBSTITUTE CLAIMS SECTION

CLAIMS

We claim:

1. A method of calibrating a camera by calculating camera parameters required to obtain geometric information of an object using projection invariable characteristic of a concentric circle comprising the steps of;

a) taking a plurality of images of a calibration pattern consisting of two or more concentric circles located at a same plane and having different radiuses at different angles to obtain images of ellipses as a result of the projection of said concentric circles;

b) calculating the central points of the projected concentric circles using a given algorithm; and

c) calculating the principal point and focal length of said camera for tracing the location of a circle in a 3D space using a nonlinear minimizing method based on the central points calculated in said step b).

2. The method of calibrating a camera according to claim 1, wherein said concentric circle includes two circles and said step b) includes the steps of:

d) calculating the central points of the two ellipses to obtain a straight line passing through said central points;

e) calculating crossing points of said straight line and said two ellipses; and

f) calculating the coordinate of the central point of said concentric circle using a cross ratio depending on the central point(0) of the concentric circle, a given point (M_∞) infinitely separated from the central point of the concentric circle on the straight line passing through the central points of the ellipses, and the crossing points of the straight line and the ellipses.

3. The method of calibrating a camera according to claim 2, wherein said step d) calculates the straight line passing through the centers of the ellipses by Equation 1:

$$(B'E' - A'F')X' + (A'D' - B'C')Y' + (D'E' + F'C') = 0 \qquad (1)$$

(where A', B', C', D', E' and F' are constants with respect to the radius of the circle and, X',Y' are the coordinates of the ellipse center)

4. The method of calibrating a camera according to claim 3, wherein said step f) calculates the coordinate of the center of the circle by Equation 2:

$$
\begin{aligned}
Cr(A, O, B, M_\infty) &= \frac{\overline{BAM_\infty O}}{\overline{BOM_\infty A}} = 2 \\
Cr(A', O, B', M_\infty) &= \frac{\overline{B'A'M_\infty O}}{\overline{B'OM_\infty A'}} = 2
\end{aligned}
\qquad (2)
$$

a\

where A,B are the coordinates of crossing points of an ellipse generated by projection of smaller circle and the straight line, and A',B' are the coordinates of crossing points of an ellipse generated by projection of an external circle surrounding the smaller circle and the straight line)

5. The method of calibrating a camera according to claim 3, wherein said step c) includes the steps of:

g) assuming that the central point and a approximate focal length obtained in said step b) as a principal point focal length;

h) estimating the location of the circle in a 3D space using said principle point and focal length ; and

i) repeating said steps g) and h) using a given nonlinear minimization algorithm using a normal vector of said concentric circle, a vertical distance from an original point and the radius of the concentric circle based on the location of the circle obtained in said step h), so that below Equation 3 is minimized.

$$
\begin{aligned}
&F(u_0, v_0, f) = \\
&\alpha\left(\overline{n_1} - \overline{n_2}\right)^2 + \beta\left(\overline{n_3} - \overline{n_4}\right)^2 + \gamma(d_1 - d_2)^2 + \lambda(d_3 - d_4)^2 \\
&+ \rho_1 \sum \left|R_{C_1}(n_1, d_1) - R_1\right| + \rho_2 \sum \left|R_{C_2}(n_2, d_2) - R_2\right| \\
&+ \rho_3 \sum \left|R_{C_3}(n_3, d_3) - R_3\right| + \rho_4 \sum \left|R_{C_4}(n_4, d_4) - R_4\right|
\end{aligned}
\qquad (3)
$$

where u_0, v_0 and f indicate a principle point and a focal length of the camera, the first two items in Equation 3 indicate that two concentric circles have the same normal vector, next two items in Equation 3 indicate that two concentric circles are located on a plane having the same length, and next four items indicate that a radius obtained from given internal parameters is same as the actual radius.

6. A system for calibrating internal parameters of a camera for calibrating parameters between an actual object and images of the object, comprising;

a camera;

a calibration pattern located on a same plane and consisting of two or more concentric circles having different radiuses, the image of which is taken by said camera; and

a controller for calculating a straight line connecting the central points of the images of ellipses obtained by projecting said calibration pattern of concentric circles to said camera at a given angle, and finding crossing points of said straight line and said projected ellipses to obtain the central point coordinate of the concentric circle using a cross ratio (Cr), and tracing the location of the circle in a 3D space based on the coordinate of the central point of the concentric circle to calculate a principal point and focal length of the camera.

7. The system for calibrating internal parameters of a camera according to claim 6, wherein said principal point and focal length are obtained using a given nonlinear minimization algorithm so that below Equation 3 is minimized.

$$\begin{aligned}
&F(u_0,v_0,f)= \\
&\alpha\left(\overline{n_1}-\overline{n_2}\right)^2+\beta\left(\overline{n_3}-\overline{n_4}\right)^2+\gamma(d_1-d_2)^2+\lambda(d_3-d_4)^2 \\
&+\rho_1\sum\left|R_{C_1}(n_1,d_1)-R_1\right|+\rho_2\sum\left|R_{C_2}(n_2,d_2)-R_2\right| \\
&+\rho_3\sum\left|R_{C_3}(n_3,d_3)-R_3\right|+\rho_4\sum\left|R_{C_4}(n_4,d_4)-R_4\right|
\end{aligned} \qquad (3)$$

where u_0, v_0 and f indicate a principle point and a focal length of the camera, the first two items in Equation 3 indicate that two concentric circles have the same normal vector, next two items in Equation 3 indicate that two concentric circles are located on a plane having the

same length, and next four items indicate that a radius obtained from given internal parameters is same as the actual radius.

8. The system for calibrating internal parameters of a camera according to claim 6, wherein said camera is a CCD camera.